

Amplitude Space Sharing among the Macro-Cell and Small-Cell Users

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Abstract—The crushing demand for wireless data services will soon exceed the capability of the current homogeneous cellular architecture. An emerging solution is to overlay small-cell networks with the macro-cell networks. In this paper, we propose an amplitude space sharing (ASS) method among the macro-cell user and small-cell users. By transmit layer design and data-rate optimization, the signals and interferences are promised to be separable at each receiver and the network sum-rate is maximized. The Han-Kobayashi coding is employed and optimal power allocation is derived for the one small-cell scenario, and a simple ASS transmission scheme is developed for the multiple small-cells scenarios. Simulation results show great superiority over other interference management schemes.

Index Terms—Amplitude space sharing, Han-Kobayashi coding, interference channel, power allocation, small-cell network.

I. INTRODUCTION

With penetration of smartphones and tablets, the crushing demands of wireless data traffic will soon exceed the capability of current homogeneous cellular architecture. To deliver high-speed transmission and consistent coverage, the multi-tier heterogeneous architecture is emerging as a promising and economically sustainable solution [1], [2]. While the macro-cell base station (MBS) provides near-universal coverage and supports fast mobility, the low power small-cell access points (SAPs) provide high-capacity transmission for hotspot zones. Generally, small-cells include technologies variously described as femto-cells, pico-cells, micro-cells and metro-cells [3]. By shrinking the transmission range and intensifying spatial reuse of the spectrum, these heterogeneous infrastructure elements can achieve significant areal capacity gain.

Operated in licensed spectrum, small-cells introduce new forms of interference to the macro-cell [4]. For example, femto-cells are typically deployed in ad hoc manner by costumers, where there is not any constraint on node positions, and they might be activated at any time. The large difference in transmission power between MBS and SAP cause asymmetric interference modes both in downlink and uplink. In some cases, we can control the mutual interference by allocate appropriate powers to MBS and SAPs; but for other cases the strong interference is inevitable, such as when the macro-cell user (MUE) is located in the macro-cell edge and the small-cell user (SUE) is located in the macro-cell center, the SUE will receive dominant interference from the MBS. Fortunately, in the latter scenarios, the SUE can still work effectively in an

underlay mode by the technique of interference cancelation.

Amplitude space sharing (ASS) means that we proactively design the transmit layers and allocate data rates of each layer in the network, so that at each receiver the interference can either be treated as noise or be decoded and canceled. Compared with the passive interference cancelation techniques [5], ASS creates the opportunities for interference cancelation and optimizes the occupied spaces of each user for maximizing the multiuser sum-rate. In the heterogeneous networks, although the MBS transmits with large power, its data rate may not be high if the MUE is in the cell edge; thus it has large potential for small-cell users to utilize the residual amplitude space. Of course, the signals and interferences can also be separated through transmit or receive beamforming by employing multiple antennas [6], [7], but the amplitude space and beam space are two kinds of complementary degrees of freedom, we concentrate on the studies of amplitude space in this paper.

With one small-cell coexisted with the macro-cell, the simultaneous communications of MUE and SUE form a basic two-user interference channel problem. The best known achievable scheme for this problem is Han-Kobayashi (H-K) coding [8], where each user divide its transmit information into private and common portions; the private information is only decoded in the intended receiver and the common information is decoded at both receivers. H-K coding is a sophisticated ASS method because it divide each user's signal into two layers and each layer has its transmit power and data rate. At the receiver, totally four layers of signals and interferences will share the amplitude space. To maximize the sum-rate of two users, we develop an unified optimization framework that not only derives classic results such as the sum-capacity in strong interference, but also obtains the best known achievable sum-rate in weak interference.

In multiple small-cells scenarios, the two-user H-K coding is not applicable. In this case, we will simplify the transmitter-side coding to just use one layer, but keep the receiver-side ASS as its various possible forms. That means, at one SUE, the interference from MBS may occupy the upper layer space; but at another SUE, the interference from MBS may occupy the lower layer space. We will allocate the transmit data rates of each user by a systematic method inspired from the two-user H-K coding.

The rest of this paper is organized as follows. In Section

II, we derive the optimal power allocation of H-K coding for private and common information in different interference scenarios. In Section III, we propose the amplitude space sharing transmission scheme in multiple small-cells environments. In Section IV, we will show the connection between network geometry and interference mode, and evaluate the performance gains of the ASS schemes over other interference coordination schemes. Finally, Section V concludes the paper.

II. OPTIMIZED H-K CODING

H-K coding defines private and common layers of transmission for each user, but it does not specify the power allocation of each layer. With different channel gains, we can optimize the power allocation scheme to maximize the sum-rate of two users.

A. Problem Formulation

The nominal model of two-user Gaussian interference channel is shown in Fig. 1, where h_{ii} denotes the direct signal link from Tx_i to Rx_i and h_{ij} denotes the cross interference link from Tx_j to Rx_i , $i, j \in \{1, 2\}$. The transmit symbol of Tx_i is x_i that is complex Gaussian and with power P_i , i.e., $x_i \in \mathbb{C}, \mathbb{E}\{|x_i|^2\} = P_i$. The received symbols of two users are

$$y_1 = h_{11}x_1 + h_{12}x_2 + z_1, \quad (1)$$

$$y_2 = h_{21}x_1 + h_{22}x_2 + z_2, \quad (2)$$

where the noise $z_i \sim \mathcal{CN}(0, N_0)$ is circular symmetric complex Gaussian with zero mean and variance N_0 .

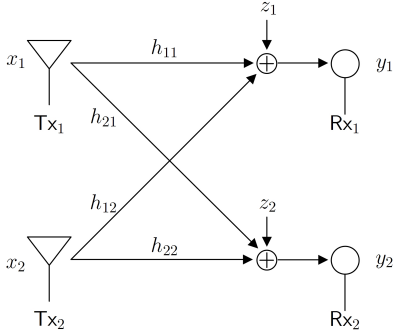


Fig. 1. Two user Gaussian interference channel model.

Define $\text{SNR}_1 = |h_{11}|^2 P_1 / N_0$, $\text{SNR}_2 = |h_{22}|^2 P_2 / N_0$ as the receiver-side SNRs of user 1 and 2, and $\text{INR}_1 = |h_{12}|^2 P_2 / N_0$, $\text{INR}_2 = |h_{21}|^2 P_1 / N_0$ as the receiver-side INRs of user 1 and 2, respectively. The private and common information are coded separately and superimposed before transmission, i.e., $x_1 = x_{1,p} + x_{1,c}$, $x_2 = x_{2,p} + x_{2,c}$. The word ‘common’ here does not mean any data-sharing between two users.

For user i , $i = 1, 2$, assume that the power allocated to the private information is $P_{i,p}$ and to the common information is $P_{i,c}$, where $P_{i,p} + P_{i,c} = P_i$. The achievable data rates of the private information and common information are denoted as $R_{i,p}$ and $R_{i,c}$, respectively. At one receiver, the common

information from the intended user and interference user are first decoded, and then the private information from the intended user is decoded while regarding the remained private layer signal of the interference user as background noise.

The achievable rates of the two private information are respectively

$$R_{1,p} = \log \left(1 + \frac{|h_{11}|^2 P_{1,p}}{|h_{12}|^2 P_{2,p} + N_0} \right), \quad (3)$$

$$R_{2,p} = \log \left(1 + \frac{|h_{22}|^2 P_{2,p}}{|h_{21}|^2 P_{1,p} + N_0} \right). \quad (4)$$

For the common information, since the data from both transmitters should be decodable at both receivers, the achievable rate region are constrained by the intersection of the two multiple-access channels capacity regions at Rx_1 and Rx_2 . Correspondingly, the achievable rates of two common information are constrained as

$$R_{1,c}^{(1)} \leq \log \left(1 + \frac{|h_{11}|^2 P_{1,c}}{|h_{11}|^2 P_{1,p} + |h_{12}|^2 P_{2,p} + N_0} \right), \quad (5)$$

$$R_{2,c}^{(1)} \leq \log \left(1 + \frac{|h_{12}|^2 P_{2,c}}{|h_{11}|^2 P_{1,p} + |h_{12}|^2 P_{2,p} + N_0} \right), \quad (6)$$

$$R_{1,c}^{(1)} + R_{2,c}^{(1)} \leq \log \left(1 + \frac{|h_{11}|^2 P_{1,c} + |h_{12}|^2 P_{2,c}}{|h_{11}|^2 P_{1,p} + |h_{12}|^2 P_{2,p} + N_0} \right), \quad (7)$$

$$R_{1,c}^{(2)} \leq \log \left(1 + \frac{|h_{21}|^2 P_{1,c}}{|h_{21}|^2 P_{1,p} + |h_{22}|^2 P_{2,p} + N_0} \right), \quad (8)$$

$$R_{2,c}^{(2)} \leq \log \left(1 + \frac{|h_{22}|^2 P_{2,c}}{|h_{21}|^2 P_{1,p} + |h_{22}|^2 P_{2,p} + N_0} \right), \quad (9)$$

$$R_{1,c}^{(2)} + R_{2,c}^{(2)} \leq \log \left(1 + \frac{|h_{21}|^2 P_{1,c} + |h_{22}|^2 P_{2,c}}{|h_{21}|^2 P_{1,p} + |h_{22}|^2 P_{2,p} + N_0} \right), \quad (10)$$

where (5), (6) and (7) construct the multiple-access channel capacity region at Rx_1 , and (8), (9) and (10) construct the multiple-access channel capacity region at Rx_2 . At both receivers, the signals of private information serve as background noise.

The optimization problem of power allocation to maximize the sum-rate can be formulated as follows,

$$\begin{aligned} & \max_{P_{1,p}, P_{1,c}, P_{2,p}, P_{2,c}} R_{1,p} + R_{1,c} + R_{2,p} + R_{2,c} \\ & \text{s.t. } P_{1,p} + P_{1,c} = P_1, \\ & \quad P_{2,p} + P_{2,c} = P_2, \\ & \quad (3), (4), (5), (6), (7), (8), (9), (10). \end{aligned} \quad (11)$$

B. Optimization Results

Consider sum-rate constraint of the two common messages, there are totally four possibilities, i.e.,

$$\begin{aligned} R_{\text{sum},c} = & \min \left\{ R_{1,c}^{(1)} + R_{2,c}^{(1)}, R_{1,c}^{(2)} + R_{2,c}^{(2)}, R_{1,c}^{(1)} + R_{2,c}^{(2)}, R_{1,c}^{(2)} + R_{2,c}^{(1)} \right\}. \end{aligned} \quad (12)$$

For each user the data rates of private information and common information are competitive since their sum power is constrained. Observing (11) and (12), we know that this is a max-min problem. The key idea in the solution process is to use perspective transformation to optimize a two-variable quadratic-fractional problem. Due to the limit space of this

TABLE I
SUMMARY OF OPTIMAL POWER ALLOCATION SCHEMES AND ACHIEVABLE SUM-RATES

Interference Modes	Conditions	$P_{1,p}$	$P_{2,p}$	R_{sum}
Very Strong	$\text{SNR}_1 < \frac{\text{INR}_2}{1+\text{SNR}_2}$ and $\text{SNR}_2 < \frac{\text{INR}_1}{1+\text{SNR}_1}$	0	0	$\log(1 + \text{SNR}_1) + \log(1 + \text{SNR}_2)$
Strong	$\text{SNR}_1 < \text{INR}_2$ and $\text{SNR}_2 < \text{INR}_1$	0	0	$\min \left\{ \log(1 + \text{SNR}_2 + \text{INR}_2), \log(1 + \text{SNR}_1 + \text{INR}_1) \right\}$
Mixed 1	$\text{SNR}_1 \geq \text{INR}_2$ and $\text{SNR}_2 < \text{INR}_1$	P_1	0	$\min \left\{ \log(1 + \text{SNR}_1 + \text{INR}_1), \log(1 + \text{SNR}_1) + \log\left(1 + \frac{\text{SNR}_2}{1+\text{INR}_2}\right) \right\}$
Mixed 2	$\text{SNR}_1 < \text{INR}_2$ and $\text{SNR}_2 \geq \text{INR}_1$	0	P_2	$\min \left\{ \log(1 + \text{SNR}_2 + \text{INR}_2), \log\left(1 + \frac{\text{SNR}_1}{1+\text{INR}_1}\right) + \log(1 + \text{SNR}_2) \right\}$
Weak	$\text{SNR}_1 \geq \text{INR}_2$ and $\text{SNR}_2 \geq \text{INR}_1$	$P_{1,p}^*$	$P_{2,p}^*$	R_{sum}^*
Very Weak	$\gamma < 1$	P_1	P_2	$\log\left(1 + \frac{\text{SNR}_1}{1+\text{INR}_1}\right) + \log\left(1 + \frac{\text{SNR}_2}{1+\text{INR}_2}\right)$

$$\gamma = \frac{\text{INR}_1 \text{INR}_2 (\text{SNR}_1 \text{SNR}_2 - \text{INR}_1 \text{INR}_2 + \text{SNR}_1 - \text{INR}_2 + \text{SNR}_2 - \text{INR}_1)}{(\text{INR}_1 - \text{SNR}_2)(\text{INR}_2 - \text{SNR}_1)}. \quad (13)$$

$$\rho = N_0 \left(\frac{\sqrt{\frac{|h_{11}|^2 |h_{22}|^2}{|h_{21}|^2 |h_{12}|^2} (|h_{12}|^2 - |h_{22}|^2) (|h_{21}|^2 - |h_{11}|^2) \frac{1}{\alpha}}}{|h_{11}|^2 |h_{22}|^2 - |h_{21}|^2 |h_{12}|^2}} - \frac{|h_{22}|^2 - |h_{12}|^2}{|h_{11}|^2 |h_{22}|^2 - |h_{21}|^2 |h_{12}|^2} \right). \quad (14)$$

paper, we do not provide detailed derivations here. The optimized results of power allocation and achieved sum-rate are listed in Table I.

According to the relationship of SNRs and INRs, we define six kinds of interference channel modes as very strong, strong, mixed 1, mixed 2, weak, and very weak. The conditions of these interference modes are also given in Table I. It should be noted that SNR_1 and INR_2 depend on P_1 , and SNR_2 and INR_1 depend on P_2 .

In weak interference mode, the optimal power allocations for the private information of user 1 and user 2 have a linear relationship, i.e.,

$$P_{2,p}^* = \alpha P_{1,p}^* + \beta, \quad (15)$$

where

$$P_{1,p}^* = \max\{0, -\frac{\beta}{\alpha}, \rho\},$$

$$\alpha = \frac{(|h_{11}|^2 |h_{22}|^2 - |h_{12}|^2 |h_{21}|^2) P_2 + (|h_{11}|^2 - |h_{21}|^2) N_0}{(|h_{11}|^2 |h_{22}|^2 - |h_{12}|^2 |h_{21}|^2) P_1 + (|h_{22}|^2 - |h_{12}|^2) N_0},$$

$$\beta = \frac{[(|h_{22}|^2 - |h_{12}|^2) P_2 + (|h_{21}|^2 - |h_{11}|^2) P_1] N_0}{(|h_{11}|^2 |h_{22}|^2 - |h_{12}|^2 |h_{21}|^2) P_1 + (|h_{22}|^2 - |h_{12}|^2) N_0},$$

and the expression of ρ is given in (14). The achievable sum-rate in weak interference mode is

$$R_{\text{sum}}^* = \log \left(\frac{C_1 C_2 \frac{(|h_{11}|^2 |h_{22}|^2 - |h_{12}|^2 |h_{21}|^2) P_{1,p} + (|h_{22}|^2 - |h_{12}|^2) N_0}{(|h_{11}|^2 |h_{22}|^2 - |h_{12}|^2 |h_{21}|^2) P_1 + (|h_{22}|^2 - |h_{12}|^2) N_0}}{(\alpha |h_{12}|^2 P_{1,p} + \beta |h_{12}|^2 + N_0) (|h_{21}|^2 P_{1,p} + N_0)} \right). \quad (16)$$

Observing from Table I we can find that, except in weak interference mode, only one layer is required to achieve the

maximal sum-rate, either private or common. In very strong and strong modes, each user only transmits common information; in mixed mode, one user transmits common information and the other user transmits private information; in very weak mode, each user only transmits private information. In the general weak mode, both users may transmit two layers of information.

Except in weak interference mode, the optimized sum-rates actually achieve the sum-capacities. The capacity regions of two user interference channel in very strong and strong modes are proved in [9] and [10], respectively. The sum-capacities in mixed and very weak modes are proved in [11]. The sum-capacity in general weak mode is still an open problem. To our knowledge, the result in Table I is the best known achievable sum-rate in weak interference mode.

III. ASS BY MULTIPLE SMALL-CELL USERS

When multiple small-cells are deployed in a macro-cell, the interference modes are more complicated. Theoretically, with K small-cells coexisted with one macro-cell, it is a $(K+1)$ -user interference channel problem. The optimal transmission scheme design is out of the scope of this paper. Instead, we use the insight gained from the optimized H-K coding to design a simple ASS transmission scheme for this kind of heterogeneous networks.

Suppose that K small-cells are randomly deployed in the coverage of the macro-cell, and each small-cell serves one SUE. Consider downlink transmission, and the uplink case can be similarly obtained. Given a position of the MUE, a two-user interference channel problem is built between the MBS-MUE link and each SAP-SUE link. Since the cross channel gains

differ a lot, the constituted link pairs might work in different interference modes.

Due to the low power of SAPs, the interference from other small-cells are considered as background noise. We first express the SNRs and INRs of each link pair as in the two-user interference channel case, and then discuss how to design the transmit data rate of each user so that the ASS scheme can work in the multiple small-cells scenarios.

Define the SNR pairs and INR pairs of the MUE and the k -th SUE as

$$\begin{aligned}\text{SNR}_{M,k} &= \frac{|h_{00}|^2 P_M}{\sum_{j=1, j \neq k}^K |h_{0j}|^2 P_{S,j} + N_0}, \\ \text{INR}_{M,k} &= \frac{|h_{0k}|^2 P_{S,k}}{\sum_{j=1, j \neq k}^K |h_{0j}|^2 P_{S,j} + N_0}, \\ \text{SNR}_{S,k} &= \frac{|h_{kk}|^2 P_{S,k}}{\sum_{j=1, j \neq k}^K |h_{kj}|^2 P_{S,j} + N_0}, \\ \text{INR}_{S,k} &= \frac{|h_{k0}|^2 P_M}{\sum_{j=1, j \neq k}^K |h_{kj}|^2 P_{S,j} + N_0},\end{aligned}$$

where P_M is the transmit power of the MBS, $P_{S,j}$ is the transmit power of the j -th SAP, $h_{k,j}$ is the channel gain from the j -th SAP to the k -th SUE for $j, k \neq 0$, and $j = 0$ denotes the MBS and $k = 0$ denotes the MUE.

If the MUE is located in the coverage of one small-cell, the link pair may work in strong interference mode; if one SAP has a closer distance to the MBS than the MUE, the link pair may work in mixed interference mode; if another SAP has a longer distance to the MBS than the MUE, the link pair may work in weak interference mode. According to the optimized H-K coding, for each pair we can design a transmission scheme that involves the optimal power and data rate allocation for the layers of each user. However, the K pairs actually share the same MBS-MUE link, thus there is only one possible transmission scheme for the MBS. For each layer of MBS's transmit signal, we can only apply the lowest data rate of the K calculated rates, otherwise there will be collision on the amplitude space at some receivers.

For simplicity, every user only transmits one layer information, if weak interference mode is encountered we use the transmission scheme in very weak mode instead, i.e., treating the interference from the other user as noise. With this assumption, there is no power allocation any more and this single layer uses full transmit power. However, whether this layer is private or common is not determined at the transmitter, it is determined at each receiver. For the same transmitted signal of MBS, it would behave as a common signal (occupy the upper layer space) at the receiver of a cell-center SUE; it would simultaneously behave as a private signal (occupy the lower layer space) at the receiver of a cell-edge SUE.

In Table I we provide the achieved sum-rate, but the data rate of each user is not specified. For different interference modes, the sum-rates are obtained under different multiple-access constraints as in (12). That means for some cases the sum-rates are obtained on the corners of the rate regions, for

other cases the sum-rates are obtained on the side edge of the rate regions.

For example, in the interference mode of mixed 1, if the first sum-rate term in the minimization is satisfied, it is on the side edge of the rate region and there are infinite combinations of the data rates of two users; if the second sum-rate term is satisfied, it is on the corner and there is only one possibility for the data rates of two users.

For the latter case, the transmission rates of the k -th link pair are calculated as

$$R_{M,k} = \log(1 + \text{SNR}_{M,k}), \quad R_{S,k} = \log\left(1 + \frac{\text{SNR}_{S,k}}{1 + \text{INR}_{S,k}}\right).$$

For the former case, we choose to maximize $R_{M,k}$ since the real transmission rate of MBS is the minimum of K calculated values, thus

$$R_{M,k} = \log(1 + \text{SNR}_{M,k}), \quad R_{S,k} = \log\left(1 + \frac{\text{INR}_{M,k}}{1 + \text{SNR}_{M,k}}\right).$$

After obtained K pairs of data rates $\{R_{M,k}, R_{S,k}\}$, the transmission rate of MBS is

$$R_M = \min\{R_{M,1}, R_{M,2}, \dots, R_{M,K}\}, \quad (17)$$

and the throughput of the whole network is

$$R_{\text{sum}} = R_M + \sum_{k=1}^K R_{S,k}. \quad (18)$$

IV. PERFORMANCE EVALUATION

In this section, we will apply the optimized H-K coding scheme to the coordinated heterogeneous networks, and compare the network throughput achieved by the ASS scheme with that of other schemes. We will start from one small-cell scenario. The relationship between the interference mode and network geometry is first shown, and then the achievable sum-rates varying with the SAP positions are demonstrated using the results of Table I. Finally, we will examine the throughput of K small-cells networks along with the increasing of K .

Throughout this section, we consider some basic network configurations as follows. The transmit power of the MBS is 46 dBm, the transmit power of the SAP is 30 dBm, and the transmit power of the user is 23 dBm. To show the performance gain brought purely by the ASS scheme, single antenna is considered both in the BS side and user side. The coverage of macro-cell is 500 m, where the measured SNR at the cell edge is 5 dB. The radius of small-cell is set as 60 m. The path loss models for MBS and SAP are from 3GPP channel models [12], i.e.,

$$PL_{\text{MBS-UE}} = 15.3 + 37.6 \log_{10}(D),$$

$$PL_{\text{SAP-UE}} = 30.6 + 36.7 \log_{10}(D),$$

where D is the distance between BSs and users, $PL_{\text{MBS-UE}}$ applies to the path losses of MBS-MUE link and MBS-SUE link, similarly $PL_{\text{SAP-UE}}$ applies to the path losses of SAP-MUE link and SAP-SUE link. To avoid near-field effect, SAP, SUE and MUE are not allowed to be close to the MBS within 35 m.

A. Network Geometry and Interference Mode

Given the position of MBS as in the center of a circular area, the positions of MUE and SAP can be anywhere in the macro-cell, while the SUE is located in the small-cell. The position distribution of these nodes and their relative distances are called network geometry.

The interference modes are determined by the relationship of SNRs and INRs. In downlink, the values of SNR_1 and INR_2 only depend on the channel gains $|h_{11}|$ and $|h_{21}|$ since they have the same transmit power P_1 . Similar dependency happens to SNR_2 and INR_1 . According to the path loss models, the reference power and path loss exponent are equal from one BS to different users, and the channel gains are inversely proportional to the distances between each BS and the two users. Thus the interference modes are determined by the relative distances of direct and cross links, i.e.,

$$\text{Strong Interference: } D_{11} \geq D_{21} \text{ and } D_{22} \geq D_{12},$$

$$\text{Mixed Interference 1: } D_{11} < D_{21} \text{ and } D_{22} \geq D_{12},$$

$$\text{Mixed Interference 2: } D_{11} \geq D_{21} \text{ and } D_{22} < D_{12},$$

$$\text{Weak Interference: } D_{11} < D_{21} \text{ and } D_{22} < D_{12}.$$

However, we cannot find a simple connection between the interference mode and network geometry in the very strong and very weak modes.

In uplink, the users are transmitters and the BSs are receivers, since the path losses from each user to different BSs subject to different path loss formulas, there is no simple relationship as well. We will illustrate the dependency through simulations.

Fix the positions of SAP, SUE, and change the position of MUE, we can observe the changes of interference modes both in the downlink and uplink transmissions. As shown in Fig. 2, the position of MUE changes across the macro-cell. We can see that totally five modes are appeared, but most areas are belonged to the mixed, weak and very weak modes, the strong mode only appears when the MUE is located in specific part of the small-cell. Fig. 3 illustrates the interference modes in uplink as the MUE changes its position. We can see that the relationship in uplink is quite different with that in downlink scenarios.

B. Comparisons with Other Schemes

In last subsection, we fix the positions of SAP and SUE and change the position of MUE across the whole macro-cell. Now, we fix the MUE and move the SAP from the cell center to cell edge (35m - 500m), while the SUE keeps relative position with the SAP, i.e., the SUE moves along with the SAP. Different interference modes will be encountered as the distance between SAP and MBS increases. The achieved sum-rate is shown in Fig. 4, where we also show the sum-capacity upper bound proved in [13], the sum-rates of ETW's power allocation scheme [13], the sum-rates of orthogonal transmission and treating interference as noise. In [13], the private information is allocated a power so that the INR of this layer signal at the other receiver would equal to 1, or

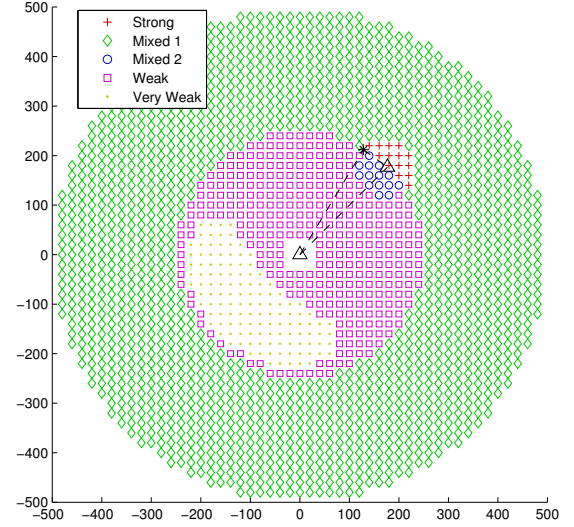


Fig. 2. The demonstration of various interference modes in accordance with the locations of MUE, downlink. The central ' \triangle ' denotes MBS, the upper right ' \triangle ' denotes SAP, and the '*' denotes SUE.

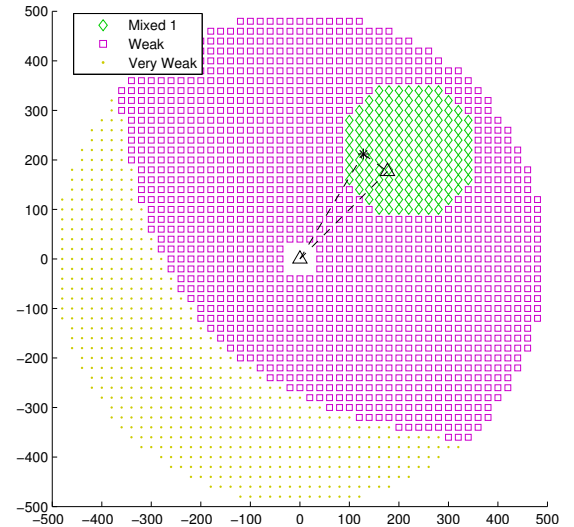


Fig. 3. The demonstration of various interference modes in accordance with the locations of MUE, uplink. The central ' \triangle ' denotes MBS, the upper right ' \triangle ' denotes SAP, and the '*' denotes SUE.

$\text{INR}_p = 1$, and it was proved that this scheme achieves the capacity region outer bound to within 1 bit. The orthogonal transmission includes the widely used fractional frequency reuse (FFR) scheme and the almost blank subframe (ABSF) scheme, etc.

We can see that as the SAP moves from cell center to cell edge, the link pair successively experience mixed 1, strong, mixed 2, weak and very weak interference modes. In every mode, the optimized H-K scheme performs the best comparing with other schemes, and achieves the upper bound in strong and mixed modes. Although ETW's power allocation scheme can achieve the capacity region outer bound to within 1 bit,

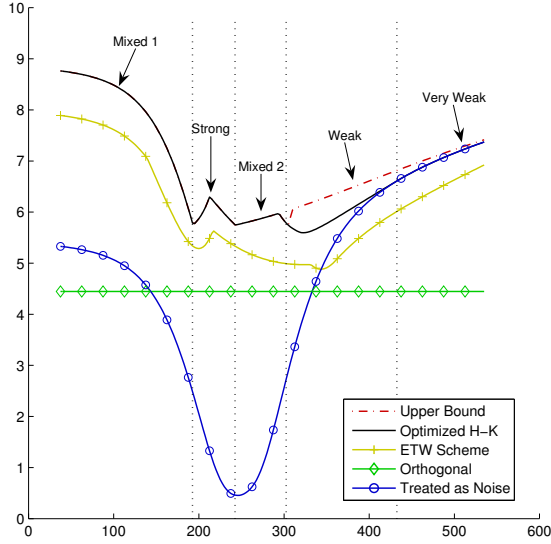


Fig. 4. The sum-rate of MUE and SUE when the SAP moves away from cell center to cell edge while the SUE keeps relative position with the SAP.

i.e., achieve the sum-capacity upper bound to within two bits, the gap to the optimized power allocation scheme is obvious. Orthogonal transmission has constant sum-rate as the SAP moves, since the direct channel gains of the MBS-MUE link and the SAP-SUE link do not change and there is no interference between these two links. Treating interference as noise works better only in very weak mode, and degrades seriously in other interference modes.

When K small-cells are randomly deployed in the macro-cell, the achieved sum-rate of the proposed ASS transmission scheme is shown in Fig. 5, where the achieved sum-rates of orthogonal transmission and treating interference as noise are also shown. In this simulation, we first set a virtual grid in the macro-cell with separations of 120 m between the rows and columns, then K intersection points are randomly selected as the locations of SAPs. In this manner, although randomly deployed, two SAPs keep a minimum distance, and this is consistent with practical cellular environments. The distance between MUE and MBS is fixed as $2/3$ of the cell radius, and the SUE is randomly located in each small-cell. From the figure we can see that, ASS scheme has great superiority over the orthogonal transmission and treating interference as noise, the sum-rate increasing slope almost doubles compared with the other two schemes. Note that in multiple small-cells scenarios, we only divide two time slots or frequency bands for orthogonal transmission, the MBS uses one slot/band and all the SAPs use another slot/band.

V. CONCLUSION

The overlay of macro-cell with multiple small-cells can achieve significant areal capacity gain. In this paper, we propose an amplitude space sharing idea to manage the inter-cell interference. Through the optimization of transmission powers and rates, at each receiver the interference is promised

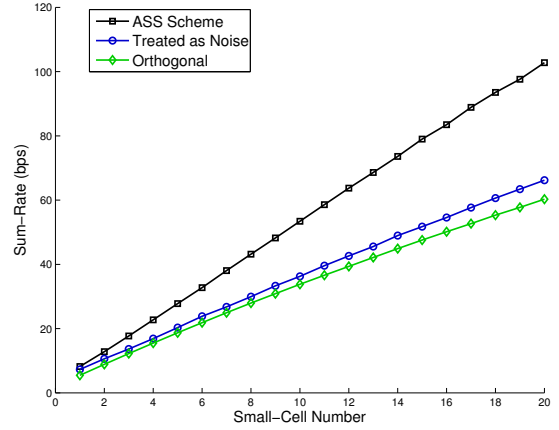


Fig. 5. The sum-rate of MUE and multiple SUEs when multiple SAPs are randomly deployed in the macro-cell.

to be separable and the network sum-rate is maximized. In one small-cell scenarios, we derived the optimal power allocation for H-K coding in different interference modes. In multiple small-cells scenarios, we developed a simple ASS transmission scheme which will double the network throughput than the time/frequency orthogonal transmissions. The principle of ASS can be easily applied in multiple-carrier and multiple-antenna systems.

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